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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000840
Canadian Building Digest, 1962-05

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Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 29

Engineering Site Investigations

Originally published May 1962

C. B. Crawford

Please note

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In urban areas building sites are seldom selected on the basis of good foundation conditions. The choice is often dictated by land cost and availability within the area selected for the structure. Unfavourable soil conditions have increased the cost of many buildings far beyond the original estimates when a proper site investigation could have provided the information required to design an economical foundation. This Digest suggests the type of information that should be obtained by a proper investigation.

The architect and his consultants are not often in a position to advise a client before land is purchased or an option taken on it. It is to the owner's advantage, however, to have expert advice on foundation conditions before purchasing, because even a superficial examination can reveal potential dangers from flooding and landslides or subsidence. Examination may also indicate potential problems with filled ground, muskeg or even permafrost. It may be possible to deal with these problems but the resultant site development costs must be recognized as a part of the land cost.

Why Investigate

There are two general reasons for investigating a building site from a foundation point of view. The main one is to permit the design of the most economical, satisfactorily safe foundation for the proposed structure. The second, which also has significant economic overtones, is to provide sufficient reliable subsurface information to permit contractors to bid on the job without having to budget for uncertainties. Ultimately the owner benefits from lower bids, better job relations, fewer extras and the absence of lawsuits.

Specifically the site investigation should reveal sufficient subsurface information for the design and construction of a stable foundation safe from both collapse and detrimental movements. It should provide enough information for the computation of lateral earth pressures and possible hydrostatic uplift; and should reveal the nature of the material to be excavated and indicate potential construction problems. Construction problems multiply when the ground water table is high, so that it is important to anticipate the worst conditions that might be expected if the investigation happens to be made in the dry season.

If municipal services are not available, the study of water supply and sewage disposal May become an important part of the preliminary investigation. Once again, the influence of a seasonally high or low ground water table should be taken into account,

Superficial Investigation

It is wise to take advantage of all sources of readily available information and advice and to plan the detailed subsurface investigation carefully. A surprising amount of information is often available, particularly in built-up areas where studies of urban geology are well advanced. Several Canadian cities now, have detailed subsurface maps; and geological reports by Federal and Provincial departments may be found in local libraries or may be purchased for a nominal sum from the appropriate source. Published information on foundation studies in any particular area may be available in technical journals.

The local building inspector or the "authority having jurisdiction," to use an expression common in building codes, will be a good source of information, particularly on where to look for boring records. Established local builders may be well acquainted with ground conditions, and especially with possible construction difficulties.

The best general indication of subsurface conditions is the performance of existing structures in the area. If it is generally good it follows that soil conditions are good, or at least that foundation designs are adequate. If performance is bad the opposite is true. In the evaluation of foundation performance, design and soil conditions must be considered together, and the result should not be extrapolated to other designs. The performance of a foundation on piles should not, for instance, be used to anticipate the performance of a mat foundation. In some regions the accepted foundation practice is based more on tradition than on fact, and although very good from a safety standpoint it may be very conservative and costly.

Detailed Investigations

There are no invariable rules for a site investigation although it should follow a logical pattern. Initially the ground is probed with penetration or shear devices in order to make a general evaluation and locate weak spots. The scope of the subsequent detailed investigation will depend on the preliminary evaluation of the site and on the size and value of the proposed structure. The nature of the structure and the size and location of any proposed cuts and fills should be known at this stage.

Even the most extensive subsurface investigation is limited to a study of a minute proportion of the soil at the site. The character of the subsoil is assessed by extrapolation. This is why it is so important to be familiar with the geology of the area. After probing, the subsoil is examined by test pits or by soil borings. These may be spaced according to a rule-of-thumb of one pit or boring for every 10,000 square feet of area, but they are more logically based on the geological evaluation of the site. A less extensive subsurface exploration is required where soil conditions are known to, be relatively uniform than in areas along rivers, lakes, estuaries and in most glaciated regions where erratic conditions may be expected.

For very large jobs it may be necessary to let a contract for boring and sampling. This should be done with the advice of a competent soils engineer who can provide supervision and inspection of the work. It is rarely advisable to let a contract on a footage basis; if boring and sampling are easy the bid price will be excessively profitable to the driller at the expense of the owner; conversely, if boring and sampling are difficult the driller may be encouraged to cut his loss at the expense of good sampling and testing techniques.

To assess foundation conditions over very large areas various forms of geophysical exploration are used. One of these, the seismic method, is based on the speed of transmission and the reflection and refraction of vibrations passing through the ground. It is carried out from the surface by measuring, with a type of microphone, the time required for an induced shock wave to echo from buried hard strata. When checked by borings the method may be very valuable for preliminary surveys, but it is not considered adequate for detailed site investigation.

Field Tests

Field tests are made in an effort to evaluate soil properties *in situ*. The boring log is the simplest field test, but its value depends very much on the skill and experience of the boring foreman. Field tests may be made using static or dynamic penetrometers, especially in cohesionless soils. In Canada, as in many other countries, the vane borer is commonly used to test cohesive soils. This device, consisting of four vertical vanes on the end of a rod, is pushed into undisturbed soil whose strength is determined by measuring the torque required to shear it. Soil permeability and pore water pressures can be measured in situ. Devices for assessing potential corrosivity are available.

One of the oldest field tests is the plate bearing test in which a plate 1 foot square is loaded in increments to measure the stress-deflection properties of the soil under the plate. The stresses in the soil depend on the width of the loaded area, so that this type of test has very definite limitations in assessing soil properties at depth. Unjustified extrapolation of the results has led to so many foundation difficulties that it is limited by the National Building Code of Canada to use for footings up to only 3 feet wide.

Full scale loading of piles and caissons is now quite common, although not enough study has yet been given to the way in which these foundation units transmit building loads to the soil. Two limitations of these full scale tests are recognized: the test of a single unit does not necessarily reflect the performance of a similar unit a few feet away; the performance of a group of units cannot usually be extrapolated directly from the performance of the single test unit. This type of field test is nevertheless the most reliable method of extending the usual site investigation.

Sampling and Testing

Field tests by themselves are not sufficient for the foundation evaluation of important sites. Direct observation of soil samples from various depths and locations is necessary for correlation with the known geology of the area and for providing the foundation engineer with a basis for improved judgement of the site conditions. Soil specimens can be analysed in detail for structural properties under a variety of loading conditions. Time or rate of loading influences can be studied and the test results can be used in rational analyses developed in the field of soil mechanics. Swelling and shrinking and frost susceptibility can be assessed and the soil can be identified and classified for comparison with similar soils on which experience is available.

It is relatively easy to obtain "disturbed" samples of soil from the ground by auger borings or by drive sampling. These should properly represent the soil at the level at which they are obtained; samples obtained by "wash borings" are not acceptable, since they may be quite misleading. Disturbed samples are useful only for determination of water content, grain size, specific gravity, mineralogy and other identifying and classifying properties. They may be used to assess potential corrosivity or chemical action. They cannot be used to assess the structural properties of the soil.

Much greater care must be exercised in the taking of "undisturbed" samples. In cohesive soils they are normally obtained by pushing a thin-walled tube with a sharpened edge into the natural soil at the bottom of a borehole. The sampler is then carefully extracted, sealed and shipped to the laboratory where the material is available in its natural state for a variety of controlled model tests. From these tests the structural properties of the soil are computed.

Depth to Investigate

When building loads are applied to the ground they do not disappear mysteriously into the soil; they set up compression and shear stresses that can be forecast with some assurance. It is known, for instance, that the compression stress under a footing at a depth equal to twice its width is only about 10 per cent of the applied stress immediately beneath it. At a depth equal to its width the stress is about one third of the applied stress (Fig. 1).

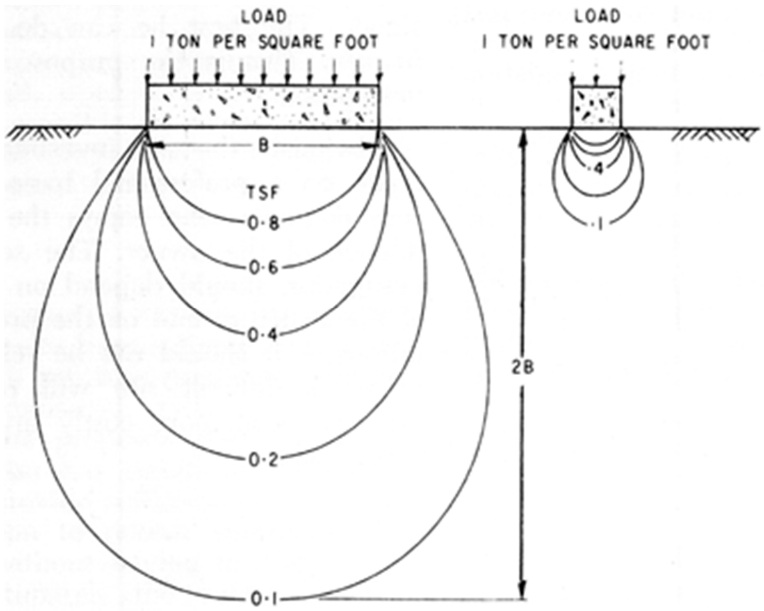

Figure 1. Lines of equal vertical stress caused by surface loads

Unless there is an unusually soft layer beneath the structure, therefore, the investigation need only be made to a depth equal to 1½ to 2 times the width of the largest footing. If, however, footings are very closely spaced the influence of one footing overlaps that of adjacent footings, and the investigation should be made to 1½ to 2 times the width of the building.

The investigation of applied stresses is especially important for the prediction of long term settlement of structures founded on clay. Under sufficiently high sustained loading clay may change volume slowly as a result of the squeezing out of water from its pores. This process, called consolidation, is a well known phenomenon. The deeper the compressible layer, the slower the process, so that structures have been known to settle for decades because of the consolidation of deep clay layers.

The carrying of building loads to great depth is not a certain cure for settlement. Many cases are on record where piers, caissons or piles were underlain by compressible soil to the detriment of the structure. Even clay seams in otherwise sound bedrock have caused concern for building foundations.

The Soil Report

No matter how complete an investigation has been, it may be of little value unless the results are properly recorded for transmission in a good report. The report should not be simply a collection of boring logs and test results, but should include adequate recommendations and advice concerning foundation design and construction.

It should provide the owner with a complete statement of the facts on which the recommendations were based and should be retained as a permanent record for future use. Although it is the owner who must decide how comprehensive the investigation should be, it is the responsibility of the consulting engineer to advise the owner in this respect.

It is quite impossible to prepare a satisfactory report on a site without taking into account the nature of the proposed construction. Consequently, the designer and the foundation engineer should work together from the beginning. This should follow through to the selection and evaluation of the foundation type. The report should then advise with regard to depth of foundation and allowable loads, taking into account uncertainties in interpreting soil properties. The amount and rate of total and differential settlement should be estimated, and this estimate should not exceed the amount permitted by the designer. Other factors such as possible corrosion and chemical attack should be evaluated.

Construction difficulties can often be anticipated during the site investigation. They may involve damage to adjacent property, instability of slope, disturbance of natural soil or frost action during construction, but it is probable that they will be related to ground water problems. The report should cover these possibilities and may even suggest the procedures to be used to avoid or reduce the difficulties.

Conclusion

The selection and design of foundations for a structure are at least as important as all other design considerations. If the structure rests on soil it is just as important to know the properties of that soil as it is to know the properties of the materials in the superstructure. Unlike the other building materials, soil properties cannot be controlled by the designer. The best he can do is assess them *in situ*. This is the purpose of the site investigation.

Obviously the site investigation should be made on a professional basis by a qualified soils engineer who enjoys the trust and confidence of the owner. The scope of the investigation should depend on the importance of the structure and on the probable site conditions - it should not be related to a fixed price. A difficult site will require a more extensive and more costly investigation than a good site.